Atty. Dkt. No.: 054821-0863

U.S. PATENT APPLICATION

for

ENERGY STORE AND METHOD FOR DETERMINING THE WEAR TO AN ELECTROCHEMICAL ENERGY STORE

Inventors: Helmut Laig-Hörstebrock
Eberhard Meissner

001.1461260.3

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CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] German Priority Application DE 102 34 032.3-34, filed 07/26/2002 including the specification, claims, and abstract, is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to a method for determining the wear to an electrochemical energy store by determining the temperature and determining a wear variable over time as a function of the battery temperature. The present invention also relates to an energy store, in particular a storage battery for motor vehicles, having temperature measurement means and having computation means, and to a system which is provided with an electrochemical energy store.

[0003] Energy stores, for example rechargeable electrochemical storage batteries, are subject to wear, in particular during discharging and charging. In addition to discharging and charging, there are also other operating conditions which speed up the wear of electrochemical energy stores. In the case of a lead-acid rechargeable battery, for example, these include the overall operating time, that is to say, the total time which has passed since it was first used, including the periods in which the rechargeable battery had no electrical load applied to it.

[0004] Furthermore, increased temperatures can exacerbate the wear during the periods when no electrical load is applied, as well as the wear caused by cyclic discharging and charging.

[0005] For the use of energy stores, it is desirable to determine the wear on the basis of the loss of storage capacity. In this case, however, the complexity of the processes in the energy store represents a problem which can be described only with difficulty by scientific methods.

[0006] For example, DE 38 08 559 C2 discloses a method for monitoring the power limit of a starter battery, in which an amount of charge balance is produced by adding up the amount of charge which has flowed in and flowed out. The state of charge of the starter battery is assessed from this, in conjunction with monitoring of a terminal voltage limit and the temperature. No statement can be made about the remaining maximum storage capacity of the energy store.

[0007] DE 195 40 872 C2 describes an empirical method for determining the aging state of a battery, in which a battery-specific family of characteristics for battery aging is predetermined. A battery aging value is determined with the aid of a family of characteristics by recording instantaneous values of battery aging influencing variables for the monitored battery. This includes, inter alia, a coefficient to take account of the temperature influence.

[0008] DE 195 40 827 A1 describes a method for determining the aging state of a battery, in which aging components which have been determined are added up to form a battery aging value. The aging components are determined on the basis of a predetermined family of characteristics and continuous measurement value monitoring on the battery. The aging components are dependent, for example, on the

characteristic amount of charge discharged in each discharge cycle, the remaining amount of charge, the rate of charging or discharging, and the temperature influence.

[0009] It is known from DE 44 14 134 A1 that the battery temperature has a major influence on the battery life, and that there is an exponential relationship between the temperature and the battery life.

[0010] US 6,369,578 B1 describes a method for determining the state of a vehicle starter battery, in which a state value is determined from the difference between a preceding state value and a wear contribution. The wear contribution is determined from a table as a function of the maximum temperature and the minimum state of charge in the interval between a preceding starting process and a subsequent starting process. The wear contributions are in this case defined such that they increase more than proportionally as the temperature rises, and also increase more than proportionally as the state of charge decreases. A wear contribution is determined for each starting process, although this does not depend on the time period since the last starting process.

[0011] Accordingly, there is a need for a method for determining the wear to an electrochemical energy store utilizing battery temperature and a wear variable that is a function of the battery temperature. There is also a need for a system and/or an energy store that incorporates such a method.

SUMMARY OF THE INVENTION

[0012] An exemplary embodiment relates to a method for determining the wear to a battery. The method includes determining the battery temperature of a battery and determining a wear variable over time as a

function of the battery temperature. The wear variable is determined as a sum of temperature-dependent wear contributions over time, with the values of the wear contributions rising more than proportionally as the battery temperature rises.

[0013] Another exemplary embodiment relates to a storage battery for motor vehicles. The storage battery includes temperature measurement means and computation means for calculating a wear variable of the storage battery. The computation means is configured to calculate the wear variable as a function of measured battery temperature using a method comprising that includes determining the temperature of a battery and determining a wear variable over time as a function of the battery temperature. The wear variable is determined as a sum of temperature-dependent wear contributions over time, with the values of the wear contributions rising more than proportionally as the battery temperature rises.

[0014] Another exemplary embodiment relates to a system provided with an electrochemical energy store. The system includes a temperature measurement device and a computation device. The computation device calculates a wear variable as a function of measured battery temperature according to a method that includes determining the temperature of a battery and determining a wear variable over time as a function of the battery temperature. The wear variable is determined as a sum of temperature-dependent wear contributions over time, with the values of the wear contributions rising more than proportionally as the battery temperature rises.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] According to a preferred embodiment, the wear of an electrochemical energy store is determined directly from a measurement of battery temperature over time, with differentiation being carried out on the basis of temperature bands. In this case, it has been found that the wear of the energy store proceeds progressively as the temperature rises above an upper limit temperature and, without any further influencing variables, the wear can be calculated directly from the temperature of the energy store.

[0016] The battery temperature can be determined relatively easily by measurement, estimation or calculation, by derivation from the known temperatures of other components, by taking into account the heat introduced and emitted by radiation or the flow of fluids, by taking account of the heat introduced by electrical power losses in the energy store, etc.

[0017] It is also possible to take account of the fact that a wear variable increases linearly with time, independently of the battery temperature over time, at battery temperatures in an intermediate range between a lower limit temperature and the upper limit temperature. Furthermore, no wear generally occurs below the lower limit temperature, so that the wear variable which was determined prior to this will remain constant in this temperature band.

[0018] In order to determine the wear variable Q_v, wear contributions q_v are preferably calculated in time intervals dt, with the time intervals dt preferably in each case being of such a duration as a function of the battery function T that the battery temperature is constant in defined tolerance bands. In the case of the procedure which is differentiated on

the basis of temperature bands, the time bands are, however, defined on the basis of the temperature intervals mentioned above. The wear variable Q_v is then determined as the sum of the wear contributions q_v in successive time intervals dt.

[0019] For battery temperatures above an upper limit temperature, the wear contributions q_v may increase progressively over time with the battery temperature. For battery temperatures in the intermediate range above the lower limit temperatures and below the upper limit temperatures, the wear contributions q_v may increase linearly with time independently of the temperature, and the wear contributions q_v may remain constant for battery temperatures below the lower limit temperature.

[0020] The temperature dependency of the wear contributions q_v may have widely differing forms, depending on the battery system. One approach that may be used is:

$$q_v = K_0 * c * \exp(-E/T)dt$$

where the wear variable Q_v is calculated from the wear contributions q_v in accordance with the formula:

$$Q_v = \sum q_v$$

and where K_0 is a proportionality factor which advantageously reflects the capacity of the energy store, and c is a dimensionless factor. The variable E indicates an activation temperature with the dimension degrees.

[0021] It is also possible to represent the temperature dependency on the wear contributions q_v in a simplified form, for example by differentiation of the temperature bands, with at least one of the

temperature bands having a more than proportional temperature dependency. By way of example, the temperature-dependent wear contributions q_v subdivided on the basis of temperature bands can be calculated in accordance with the formulae:

$$q_v = K_0 * A * (1 + a * T + b * T^2)dt$$
$$\text{for } T \geq T_0$$
$$q_v = K_0 * B * (T - T_1)dt$$
$$\text{for } T_1 < T < T_0$$
$$q_v = 0$$
$$\text{for } T \leq T_1$$

where the coefficient K_0 is a proportionality factor which advantageously reflects the capacity of the energy store. The coefficients A and B are proportionality factors, which may be chosen differently for different temperature bands. The variables in the equations are the battery temperature T in Kelvin [K] and the time t in hours [h].

[0022] The parameters A, B, a, b have the following dimensions: A [h^{-1}], a [degrees^{-1}], b [degrees^{-2}], B [$\text{degrees}^{-1}/h$]. The limit temperatures T_1 and T_0 are measured in Kelvin [K].

[0023] Different wear mechanisms frequently occur in the temperature bands. The constants c and E and A, B, a, b may therefore have different values in different temperature bands.

[0024] The storage capacity of the electrochemical energy store can advantageously be determined from a wear variable Q_v determined in this way by relating the wear variable Q_v to the storage capacity Q_N of the energy store at an earlier time than the time which is applicable to the wear variable Q_v. The storage capacity of the energy store in the new

state, that is to say the initial capacity of the energy store, is preferably chosen as the reference.

[0025] The present storage capacity of the electrochemical energy store can then be determined from the difference between the initial capacity of the energy store in the new state and the wear variable.

[0026] The present storage capacity can therefore be determined relatively reliably with little computational effort and by simple continuous temperature measurement.

[0027] It is particularly advantageous to link the calculated wear variable to further state variables which describe the state of the energy store, and to determine a linked wear variable Q_v from this. The further state variables may be determined using one or more different methods for determining the wear to an electrochemical energy store. Methods are preferably used which take account of other effects that contribute to the wear of electrochemical energy stores than the temperature dependency of the time-dependent wear. A measure for the present storage capacity can be calculated by subtraction of the linked wear variable from the initial capacity of the electrochemical energy store.

[0028] According to an exemplary embodiment, an energy store includes a computation means or device for calculation of the wear variable as a function of the measured battery temperature on the basis of the method described above, for example by suitable programming of a microprocessor or microcontroller system. According to another exemplary embodiment, a system is provided or equipped with an electrochemical energy store, in which a computation means or device is provided for calculation of the wear variable as a function of the measured battery temperature on the basis of the method described

above, for example by suitable programming of a microprocessor or microcontroller system.

[0029] The present invention will be explained in more detail in the following text with reference to various exemplary embodiments.

[0030] A differential wear contribution q_v is determined as a function of the present battery temperature T. A wear variable Q_v, which is the time integral of the differential wear contributions q_v, is determined by adding up or summing the wear contributions q_v. Linked to the capacity of the storage battery in the new state, this wear variable Q_v is a measure of the storage capacity of the energy store.

Example 1

[0031] It has been found that wear which increases progressively as the battery temperature T rises can be observed at relatively high battery temperatures T above an upper limit temperature T_0 in a time interval dt of a specific duration. For medium battery temperatures T below the upper limit temperature T_0 and above a lower limit temperature T_1, the wear in a time interval dt with a specific duration is linearly dependent on the temperature, and increases linearly as the time passes. No significant wear occurs at low battery temperature T below the lower limit temperature T_1.

[0032] The wear to an electrochemical energy store is thus determined differentiated on the basis of the stated temperature bands. For time intervals dt in which the temperatures T are approximately the same within a tolerance band, wear contributions q_v are calculated in accordance with the following formulae:

$$q_v = K_0 * A * (1 + a * T + b * T^2)dt$$

for $T \geq T_0$

$$q_v = K_0 * B(T - T_1)dt$$
$$\text{for } T_1 < T < T_0$$
$$q_v = 0$$
$$\text{for } T \leq T_1.$$

In this case, K_0 is a proportionality factor which advantageously reflects the battery size, the battery capacity and similar features, and which may be chosen differently for the different temperature bands. However, the proportionality factor K_0 is preferably chosen to be equal to the storage capacity Q_N of the energy store in the new state, for all temperatures. The proportionality factor K_0 then corresponds to the initial capacity of the energy store.

[0033] The time parameter A, which may assume different values for different temperature bands, has the dimension h^{-1}. The first temperature coefficient a has the dimension degrees^{-1}, the second temperature coefficient b has the dimension degrees^{-2}. B is a time temperature parameter with the dimension degrees^{-1}/h. The limit temperatures T_1 and T_0 are measured in K. The variables in the equations mentioned above are the temperature T in °C and the time t in hours [h]. The temperature of the energy store can be measured directly on the energy store, or can be estimated or calculated from other variables. The battery temperature T can be derived from known temperatures of other components. The amount of heat introduced and emitted by radiation or the flow of fluids can also be taken into account, or the amount of heat introduced by electrical power losses in the energy store can be taken into account. Further methods for determining a battery temperature T can be used equally well.

[0034] It has now been found that the wear variable Q_v calculated from the sum of the wear contributions q_v expresses the loss of storage

capacity of an electrochemical energy store. The present storage capacity can thus be determined from the wear variable Q_v by relating the wear variable Q_v to the storage capacity Q_N of the energy store at an earlier time, for example by relating it to the initial capacity of the energy store in the new state. The wear variable Q_v is preferably set to the value zero at this time. The present storage capacity of the energy store can thus be determined by simple temperature measurements and with little computation effort by continuously determining the wear variable Q_v, starting from the new state, throughout the entire operation of an energy store. This is done simply by calculating the difference between the wear variable Q_v and the storage capacity Q_N of the energy store at an earlier time, preferably the initial capacity in the new state.

[0035] The following parameter and coefficient values have been found to be advantageous for a lead-acid rechargeable battery:

Time parameter $A = 2.8 \cdot 10^{-5}$ [h^{-1}]
First temperature coefficient $a = 5.7 \cdot 10^{-2}$[degrees^{-1}]
Second temperature coefficient $b = 1.1 \cdot 10^{-3}$[degrees^{-2}]
Time temperature parameter $B = 2.7 \cdot 10^{-7}$[degrees]
Lower limit temperature $T_1 = 0°C = 273$ K
Upper limit temperature $T_0 = 25°C = 298$ K.

Example 2:

[0036] If the wear contributions q_v are described by the exponential function described above, it has been found, for example, for a lead-acid rechargeable battery, that the constants c = 123 and E = 5000 degrees represent a good guideline value for the wear, so that this results in a wear contribution of $q_v = 132 * K_0[Ah] * \exp(-5000/T)$ as the loss per hour [h] in [Ah/h]. If a temperature profile on the storage battery throughout the day is, for example assumed to be 25°C for 22 hours and

60°C for 2 hours, then the ratio of the wear variable Q_v to the proportionality factor Q_v/K_0 becomes 8.4% per annum.

[0037] Since, apart from the temperature influence, there are also other aspects which contribute to the wear of electrochemical energy stores, such as the rate of chargeable discharge, it is advantageous to link the wear variable Q_v to further state variables which have been determined using other methods for determining the wear, in particular methods which take account of effects other than the temperature influence which contribute to the wear.

[0038] It is important to note that the construction and arrangement of the elements of the energy store as shown and described in the preferred and other exemplary embodiments is illustrative only. Although only a few embodiments of the present inventions have been described in detail in this disclosure, those skilled in the art who review this disclosure will readily appreciate that many modifications are possible without materially departing from the novel teachings and advantages of the subject matter recited herein. It should be noted that the elements and/or assemblies of the system may be constructed from any of a wide variety of materials that provide sufficient strength or durability. Other substitutions, modifications, changes and omissions may be made in the design, operating conditions and arrangement of the preferred and other exemplary embodiments without departing from the scope of the present invention.